Project Title: **Sacramento River Nutrient Change Study: Using Changes in Nutrient Loading and Transport to Test Hypotheses about Potential Nutrient Management Actions**

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Estimated Start Date: 07/02/2019

Estimated End Date: 04/30/2023

Primary Science Focus Area: Interactions between stressors, managed species, and communities

Project Description

Our project addresses the priority science topic "Interactions between stressors, managed species, and communities". We will take advantage of changes in nutrient loading and transformations in the Sacramento River and river channels in the eastern Delta to study the response of phytoplankton to a range of nutrient loads and forms, as well as environmental factors including light, turbidity, water residence time, and grazing by zooplankton and clams. Changes in nutrient loading will occur due to infrastructure upgrades at the Sacramento Regional Wastewater Treatment Plant (SRWTP), and due to operations of existing Delta water conveyance infrastructure. Our project design makes use of these already-planned operations to conduct a multi-part adaptive management experiment to inform future nutrient management in the Delta.

Purpose and Need

While the importance of nutrients for phytoplankton growth and biomass has been intensely studied globally over the past century (Ivlev 1966, Sakamoto 1966, Ryther and Dunstan 1971, Dillon and Rigler 1974, Clasen 1980, Canfield and Bachmann 1981, Moore et al. 2013) the role of nutrients in the regulation of phytoplankton in the Sacramento River - San Joaquin River Delta (hereafter, the "Delta") is not well characterized, and creates challenges for water quality regulators and organizations that manage nutrient loads to the Delta and its tributaries. In recent years, several publicly owned treatment works (POTWs) in the Delta have undertaken costly major process upgrades to reduce their loading of dissolved inorganic nitrogen (DIN) to the Delta. The environmental outcomes of the nitrogen load reductions currently completed or underway are not yet clear, although they are being investigated by projects such as the Delta Science Program's Operation Baseline. A major uncertainty regarding Delta nitrogen loading is whether, following the current round of POTW nitrogen load reductions, further nitrogen reductions from POTWs or other sources may be considered in order to achieve specific measurable benefits. As discussed in the Central Valley Regional Water Quality Control Board's Delta Nutrient Research Plan (CVRWQCB 2018), additional scientific investigations are needed to guide the development of Delta nutrient objectives. For example, will a substantial reduction in DIN concentrations have a positive, neutral, or negative effect on desirable phytoplankton growth in the Delta? And more broadly, what is the relative importance of nutrient concentrations, water transport rates, and light levels (irradiance), in supporting desirable phytoplankton growth? Given that the cost of future POTW upgrades would cost billions of dollars, there is great value to research experiments that can be conducted now in order to better understand the potential effects of future nutrient management actions. Accordingly, we propose to use an adaptive management approach in this proposed project.

Our proposal addresses key scientific uncertainties and fills important information gaps identified in the Delta Nutrient Research Plan (DNRP, CVRWQCB 2018. Specifically, this project will address, in part, six management sub-questions posed in the DNRP.

1. What are the main factors affecting potential nutrient-related effects and how does the relative importance of these factors vary with space and time? (Delta Nutrient Research Plan, Table 1, p. 23)
2. What are the important processes that transform nutrients in the Delta and what are the rates at which these processes occur? (Delta Nutrient Research Plan, Table 1, p. 23)
3. Can nutrient management in the northern Delta (e.g., Yolo Bypass, Sacramento River, and Sacramento Deep Water Ship Channel) increase abundance or nutritional quality of pelagic phytoplankton? (Delta Nutrient Research Plan, Table 1, p. 23)
4. What is the level and type of change in nutrients needed to affect change in HABS, macrophytes, or phytoplankton abundance? (Delta Nutrient Research Plan, Table 1, p. 23)
5. What are the most likely alterations in nutrient conditions due to climate change, Delta habitat restoration, and changes in nitrogen forms and loads? (Delta Nutrient Research Plan, Table 1, p. 24)
6. What nutrient levels are needed to support adequate primary productions and a healthy food web, particularly for endangered fish species? (Delta Nutrient Research Plan, Table 1, p. 24)

Best Available Science and Conceptual Models

As described above, water and nutrients from the Sacramento River enters Georgiana Slough, and, via the Delta Cross Channel, the North Fork Mokelumne River and South Fork Mokelumne River, providing an opportunity to test the effects of changes in water transit time, depth, light, and nutrient loading on phytoplankton and zooplankton productivity and biomass. High frequency boat mapping, performed by the USGS in support of the Delta Regional Monitoring Program, is able to detect patterns in numerous aquatic variables in these side channels, including nutrient concentrations, turbidity, and chlorophyll a (Figure 2). Biogeochemical model predictions (Zhang et al. 2018) suggest that EchoWater Project upgrades to the SRWTP will result in substantial changes in nutrient concentrations in these side channels (Figure 3). The EchoWater Project upgrades will occur in stages, resulting in four distinct nutrient loading scenarios: Current, BNR Part 1, BNR Part 2, and EVR (Figure 4). During BNR Part 1 and BNR Part 2, the ammonia load from SRWTP will decrease, while the nitrate load will increase somewhat, resulting in a net decrease in dissolved inorganic nitrogen load. During the EVR diversions the load of ammonia and nitrate from SRWTP will be zero, providing an opportunity to investigate the potential impacts of nutrient load reductions that are lower than those mandated in SRWTP's current NPDES permit.

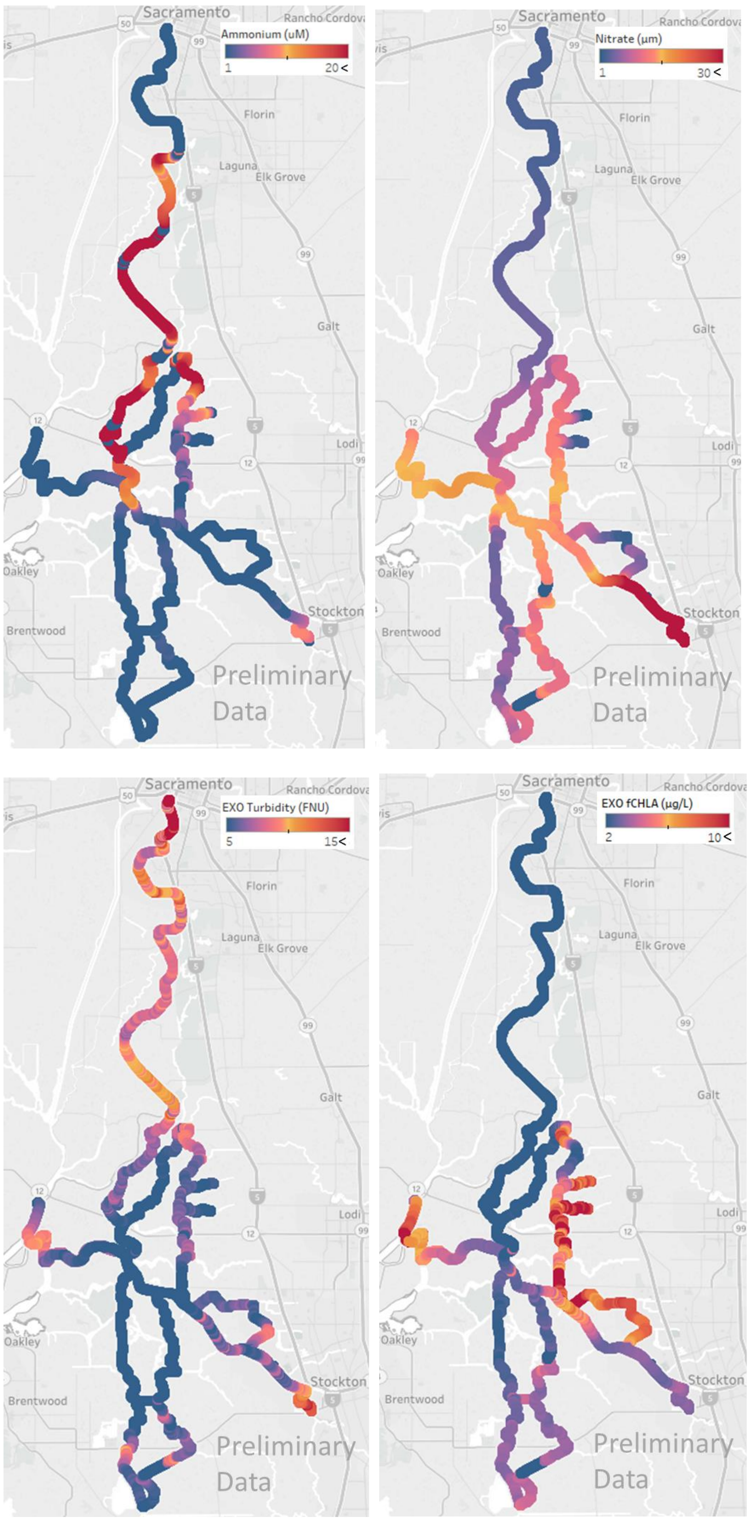

Figure 2. USGS high frequency mapping plots for the lower Sacramento River and the lower Mokelumne River-San Joaquin River systems, when the Delta Cross Channel was open, showing ammonium(top left), nitrate (top right), turbidity (bottom left), and chlorophyll (bottom right). Data from separate transects on the Sacramento River (7/24/2018) and Mokelumne-San Joaquin River (7/25/2018) are combined.

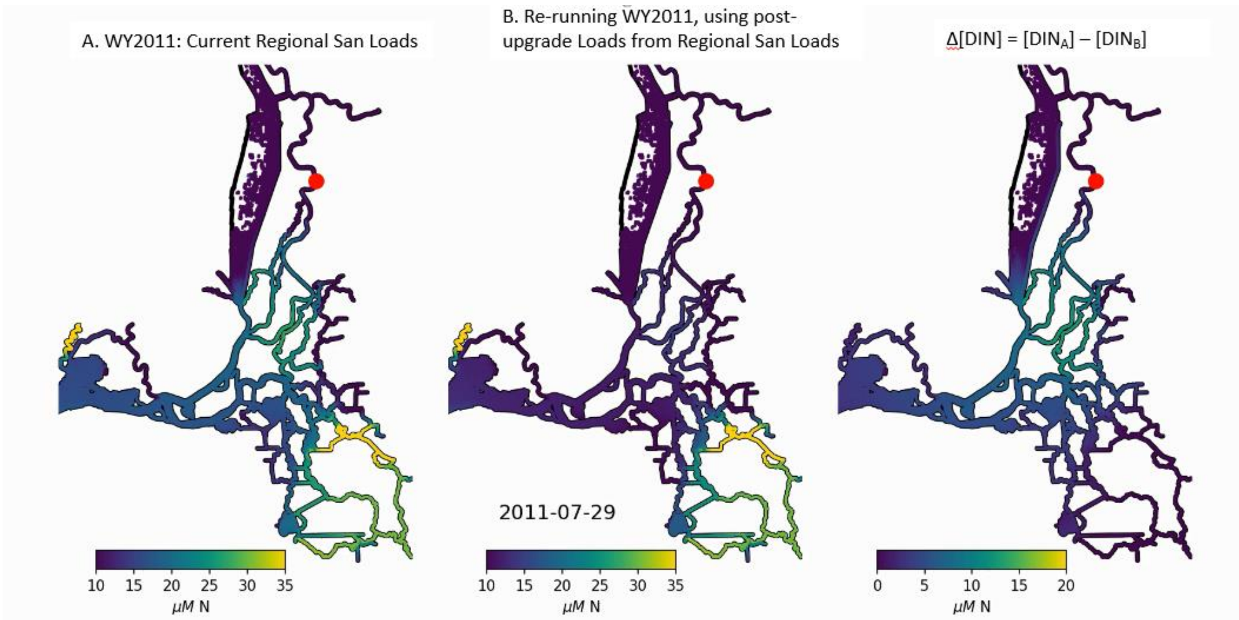

Figure 3. Model output from the SFEI Biogeochemical Model showing the movement of nutrients from the Sacramento River into the Mokelumne River system, showing model output on July 29, 2011 (Zhang et al. 2018). Legends show dissolved inorganic nitrogen (DIN) in um. Map A shows current DIN load, Map B shown the predicted DIN load after the EchoWater Project upgrade (equivalent to scenario BNR Part 2 in Figure 4), and Map C shows the difference between A and B. Map C suggests that the zone of greatest difference in loading may be in the mainstem Sacramento River and its side channels between Freeport and Rio Vista, including Georgiana Slough, the North Fork Mokelumne River, and South Fork Mokelumne River. Note that 2011 was a wet water year, so the Yolo Bypass was still flooded in July.

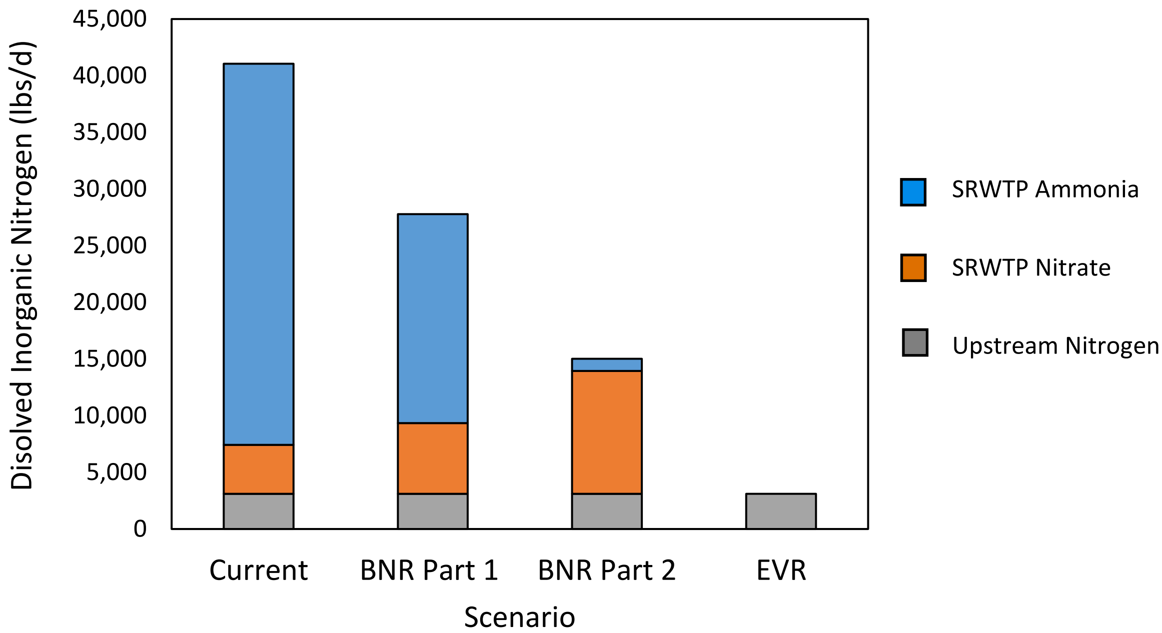

Figure 4. Predicted change in Sacramento River Nutrient loads related to the EchoWater Project at the Sacramento Regional Wastewater Treatment Plant (SRWTP). The BNR Part 1 scenario represents loading when the first part of the Biological Nutrient Removal process is online. The BNR Part 2 scenario represents loading when the second part of the Biological Nutrient Removal process is online. The EVR scenario represents loading during an Effluent Valve Replacement event, part of the upgrade construction during which wastewater effluent is stored at the treatment plant for up to 48-h, creating a wastewater-free parcel of water in the Sacramento River. Average daily dissolved inorganic nitrogen load entering the Sacramento River upstream of SRWTP are shown at the mean concentration for July (about 3,000 lbs/d), but the annual daily average upstream nitrogen load in the Sacramento River is higher at 18,500 lbs/d. Upstream dissolved inorganic nitrogen (DIN) data were collected as part of Regional San's monthly compliance monitoring at Freeport Bridge, in July, from 2014 to 2017..

Under our conceptual model, the factors of transit time, light, and nutrient loading will result in different outcomes for phytoplankton productivity and biomass occurring in the side channels compared to those living in mainstem Sacramento River. In the mainstem Sacramento River, where water depth is sufficient to make light limiting to phytoplankton growth (AMS 2017), we predict that decreased nutrient loading will have little effect on phytoplankton biomass or the higher levels of the aquatic food web (Figure 5). However, in the side channels, where a combination of decreased depth, increased transit time, and decreased turbidity may increase light availability (i.e., euphotic zone depth), we predict that phytoplankton productivity and biomass will be regulated by nutrient availability. Under scenarios will lower nutrient loading, we would expect to see less phytoplankton growth and biomass than under the current loading scenario. The diagrams in Figure 5 assume that nutrient loading from other sources upstream of Freeport are constant across situations, and that during the summer SRWTP effluent is a high proportion of the total nutrient load to the Sacramento River (see Figure 4). The diagrams assume a time frame of days, during which increases in phytoplankton and zooplankton growth rates would be detectable, and potentially also changes in phytoplankton biomass. However, changes in zooplankton abundance and clam biomass would be minimal during this short time period and difficult to detect. These diagrams do not make an assumption about whether increased phytoplankton biomass would be in the form of beneficial or harmful algal species, but we would be able to observe any changes through the high frequency boat mapping surveys, and through phytoplankton enumerations (species counts and biomass). Intermediate reductions in effluent nutrient loading, as will occur with the two phases of the Biological Nutrient Removal process, are not shown in this figure, but changes in phytoplankton biomass under situations with additional light are expected to show intermediate phytoplankton growth and biomass at levels between the nutrient loading scenarios shown in Figure 5. It is worth noting that while depth in the mainstem Sacramento River becomes shallower near Isleton, suggesting that phytoplankton growth could potentially increase there, the water in this region experiences more tidal reversals and mixing with Cache Slough water that would mask our ability to track phytoplankton growth through the lower Sacramento River.

We predict a set of gradients that may occur along the length of the rivers in our study area, including depth, transit time, turbidity, euphotic zone depth, water temperature, salinity, nitrate, ammonia, Chlorophyll, proportion of diatoms (as opposed to blue-green algae), zooplankton biomass, and clam biomass (Figure 6). Changes in nutrient loading from SRWTP will be apparent in the mainstem Sacramento River, but are unlikely to manifest in changes in phytoplankton response until the water reaches the river side channels, where other key factors, namely depth, transit time, and euphotic zone depth are favorable for phytoplankton growth. It is worth noting that if the Delta Cross Channel should close immediately after a wastewater-free parcel of water enters the North Fork and South Fork Mokelumne Rivers, then the outcomes for phytoplankton may be more pronounced than for passage through Georgiana Slough. The trends should be in the same direction as predicted in each panel, but would provide an even stronger test of our mechanistic assumptions since transit time would become very long, allowing more time for settling of turbid material, and for accumulation of phytoplankton biomass. An area of uncertainty is, if phytoplankton production increases, whether it will be comprised of beneficial types, or potentially harmful types such as Microcystis. We have taken this into account in our experimental design and sampling methods and allowed for more intensive sampling if visual inspection suggests the presence of harmful algal types.

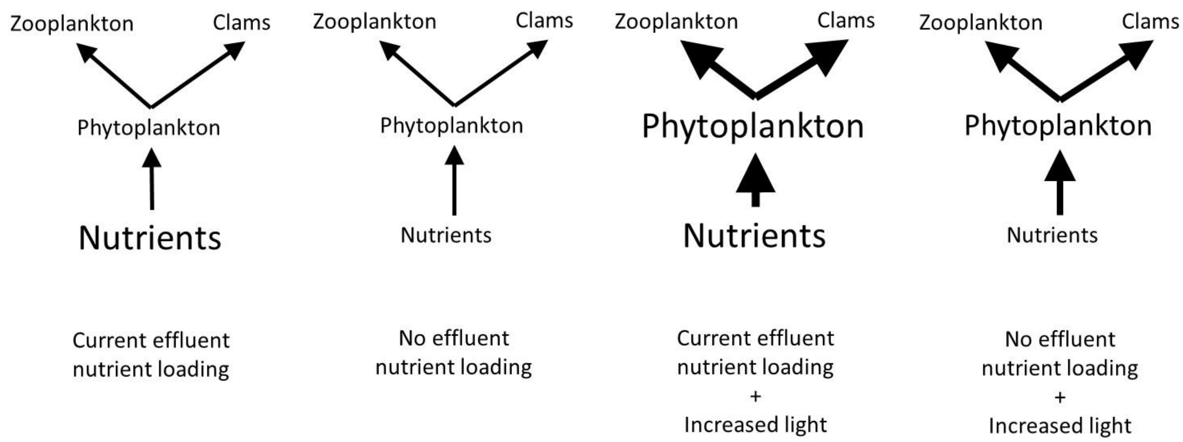

Figure 5. Food web diagrams showing potential nutrient load (focusing on dissolved inorganic nitrogen, DIN) and biomass transfer under four situations: (1) Current effluent nutrient loading, (2) No effluent loading, as will occur during Effluent Valve Replacement diversions, (3) Current loading plus increased light availability, and (4) No effluent loading plus increased light availability. The size of the text indicates the relative nutrient load or biomass, and the thickness of the arrows indicates the relative rate of transfer (as productivity (i.e., growth)). Outcomes for intermediate nutrient loading scenarios BNR Part 1 and BNR Part 2 are anticipated to be intermediate to the more extreme contrast between current effluent nutrient loading and the EVR no effluent loading scenario.

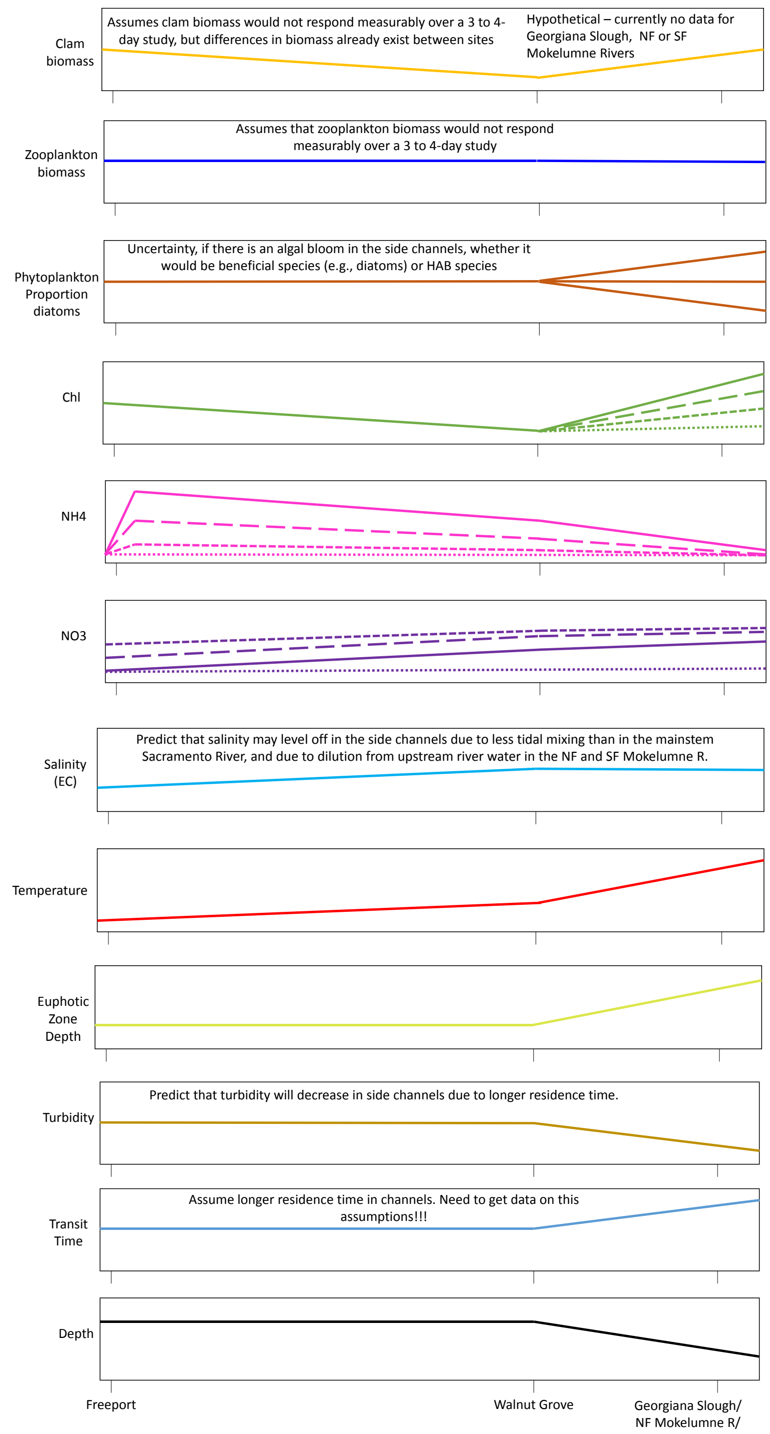

Figure 6. Conceptual model of gradients along the Sacramento River from Freeport to Walnut Grove, and in three side channels downstream: Georgiana Slough, and through the Delta Cross Channel to the North Fork and South Fork Mokelumne Rivers. Hypothetical results are as shown for the four nutrient loading scenarios in Figure 4: Current nutrient concentrations and loads from the Sacramento Regional Wastewater Treatment Plant (SRWTP) (solid line), BNR Part 1 (large dashed line), BNR Part 2 (small dashed line), and EVR, with no nutrient loading from SRWTP, during an up to 48-hour diversion for the Effluent Valve Replacement Project (dotted line). Figure inspired by Kimmel et al. (1990), Fig. 6.3. There may be somewhat different responses in the three side channels, due to differences in depth and transit time, but these differences are not accounted for in this figure.

The drawback of the conceptual model described above is that water is expected to pass through the side channels in a matter of days during the summer, so there will not be a lot of time in which phytoplankton and zooplankton can respond to changing nutrient loading before the water is mixed into the San Joaquin River system. To provide an opportunity to investigate the Delta under a longer period of nutrient reduction, and as a proxy for conditions in peripheral areas of the Delta where nutrients may become limiting, we have included testing a scenario under which the DCC is closed for an extended period. Although prolonged closures of the DCC typically only occur in winter, when phytoplankton growth rates are reduced, phytoplankton uptake is expected to gradually deplete nutrients during the long experimental period. This may replicate conditions of nutrient drawdown that are known to occur during a large algal bloom (Figure 7), as has been displayed under laboratory conditions (Dugdale et al. 2013). Following a DCC closure, the water residence time in these channels will increase markedly, providing a unique opportunity to potentially investigate a residence time that exceeds the time it takes for phytoplankton to fully deplete all the nutrients from the water column. In order to ensure that the study is focused on Sacramento River water and the drawdown of its nutrients, this work will commence immediately after the DCC closes (likely in early December). This will allow for adequate data collection throughout the winter and before a potential flushing of the Mokelumne River system during a winter storm.

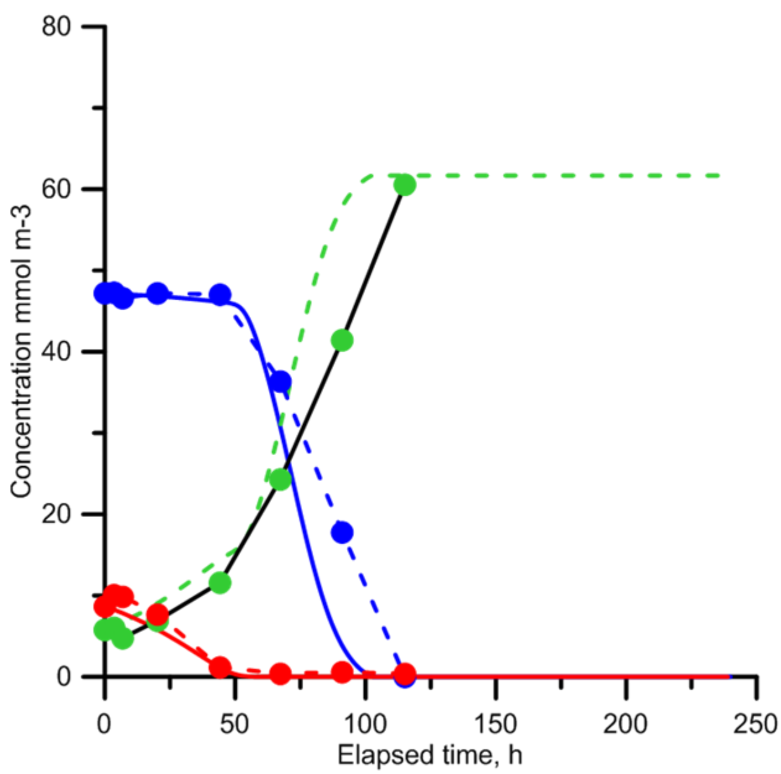

Figure 7. Model results and comparison experimental enclosure data showing the relation of declines in ammonium (red) and nitrate (blue) over time in comparison to an increase in chlorophyll (green) in water collected from the North Delta. From Dugdale et al. (2013).

Questions/Hypotheses

The questions and the associated hypotheses we pose with this project are listed below:

Question 1: Will a substantial reduction in DIN concentrations have a positive, neutral, or negative effect on desirable phytoplankton growth in the Delta?

> Hypothesis 1: A substantial reduction in DIN concentration will have a neutral impact on phytoplankton growth in the Delta.

Question 2: How will low and high irradiance combined with a substantial reduction in DIN concentrations impact phytoplankton growth in the Delta?

> Hypothesis 2A: A substantial reduction in DIN concentration will have a neutral impact on phytoplankton growth in the Delta under low irradiance.
>
> Hypothesis 2B: A substantial reduction in DIN concentration will have a negative impact on phytoplankton growth in the Delta under high irradiance.

Question 3: How will increased residence time combined with a substantial reduction in DIN concentrations impact phytoplankton growth and biomass accumulation in the Delta?

> Hypothesis 3A: A substantial reduction in DIN concentration will have a neutral impact on phytoplankton growth in the Delta under low residence time.
>
> Hypothesis 3B: A substantial reduction in DIN concentration will have a negative impact on phytoplankton growth in the Delta under high residence time.

Question 4: How will grazing pressure change and impact phytoplankton biomass accumulation with increased irradiance and water residence times under high and low nutrient scenarios?

> Hypothesis 4A: Under low residence time and low irradiance, grazing pressure will not impact phytoplankton biomass accumulation with either low or high DIN concentrations.
>
> Hypothesis 4B: Under high irradiance and low residence time, grazing pressure will not impact phytoplankton biomass accumulation with either low or high DIN concentrations.
>
> Hypothesis 4C: Under high residence time and high irradiance, grazing pressure will negatively impact phytoplankton biomass accumulation with high DIN concentrations but not with low DIN concentrations.

In order to test these hypotheses we will **conduct three 1-week and a fourth longer river sampling campaigns**, timed to sample the different nutrient load reduction scenarios, and also to incorporate sampling periods midway through the EchoWater Project upgrade, and after the nutrient reduction part of the EchoWater Project upgrade is fully operational. Note that the most extreme nutrient reduction scenario occurs at the beginning of the project, because we are taking advantage of some treatment process interruptions, which will occur as part of the construction process, and will allow us to study a scenario with no effluent-derived nutrients entering the river.

1. Regular Effluent-Nutrients versus Complete Effluent-Nutrient Reduction – Scheduled wastewater effluent diversions will occur in **summer of 2019** during the Effluent Valve Replacement (EVR) project, part of the EchoWater Project upgrade at the SRWTP. During an EVR diversion <u>no</u> treated effluent will enter the Sacramento River for a period of up to 48 hours. Based on prior research (Kraus et al. 2017) this should create a parcel of effluent-free river

water over six miles long in the Sacramento River, which we will compare with the regular SRWTP operations occurring at that time.

2. Partial Effluent- Nutrient Reduction: Mid-EchoWater - Conducted in the **summer of 2020**, there will be a moderate reduction in Sacramento River nutrient concentrations when roughly half of the EchoWater Project Biological Nutrient Removal (BNR) process is initiated.
3. Substantial Effluent-Nutrient Reduction: Post EchoWater – Conducted in the **summer of 2021** following the completion of the EchoWater Project BNR process, which will further reduce average nutrient concentrations in the Sacramento River.
4. Gradual Nutrient Reduction - In **winter/spring 2020**, during the seasonal closure of the DCC, we will study the effect of a long slow drawdown of nutrient concentrations by phytoplankton and denitrification in the Mokelumne River, to what may be growth-limiting nutrient conditions.

Objectives

Objective Number*	Objective	Anticipated Outcomes
1	Determine the main factors affecting potential nutrient-related effects and how the relative importance of these factors varies in the north-east Delta over time.	Study results will describe the relative importance of light, water transport, zooplankton and clam grazing, on phytoplankton growth at multiple nutrient concentrations.
2	Determine the rate of nutrient transformations in the Delta and the influence of multiple important processes on these rates.	The important processes regulating nutrient transformation will be identified by relating monitored nutrient, water transport, and chl-a data from different ambient conditions, within a biogeochemical model.
3	Determine if nutrient management in the Sacramento or Mokelumne Rivers can increase the abundance or nutritional quality of pelagic phytoplankton.	Results will describe changes to phytoplankton abundance and species composition in the river resulting from reduced nutrient concentrations, compared to high-nutrient control water.
4	Determine if the change in nutrient levels or forms in the Sacramento River was sufficient to change phytoplankton and, potentially HAB, abundances.	Monitoring phytoplankton growth, species composition, and biomass during rapid and gradual changes in nutrient concentrations and forms, will identify if changes occurred at particular nutrient concentrations.
5	Determine the most likely alterations in nutrient conditions due to climate change, Delta habitat restoration, and changes in nitrogen forms and loads?	By determining nitrification rates across a range of nutrient concentrations and habitat types, we will provide modelers the information needed to predict outcomes from potential additional nutrient management options.
6	Determine what nutrient levels are needed to support adequate primary production and a healthy food web, particularly for endangered fish species?	We will investigate how nutrient concentrations and other factors regulate phytoplankton and zooplankton growth and abundance in the Delta, describing if nutrient reductions alter the pelagic food supply for endangered fish.

Study Design and Methods

Our project uses field work, laboratory analyses, and data analyses to determine phytoplankton responses to a range of nutrient loading scenarios, as well as other environmental factors. We will use a range of methods, including high frequency fixed stations for water quality, mobile high frequency boat sampling of water quality, “grab” sampling of water quality, phytoplankton biomass, zooplankton biomass, and clam biomass, and phytoplankton nutrient uptake assays (including carbon uptake to determine growth rates). See Figure 8, project specific map, for locations of river segments to be mapped, and water quality/plankton/clam sample site locations. Sampling methods will be consistent across the three 1-week and fourth longer river sampling campaigns, but the number of sampling sites will vary with the nutrient loading scenario being examined, as follows:

(1) Regular Effluent-Nutrients versus Complete Effluent-Nutrient Reduction (summer 2019) - We will sample at a total of 12 “grab sample” stations, three along the Sacramento River, three along Georgiana Slough, three along the North Fork Mokelumne River and three along the South Fork Mokelumne River. The high frequency sampling boat will sample these river segments daily during the week of study. Note that the exact location of the sampling sites may as it depends on Sacramento River discharge rates during the time of sampling.

(2) Partial Effluent-Nutrient Reduction: Mid-EchoWater (summer 2020) - We will sample at a total of 12 “grab sample” stations, three along the Sacramento River, three along Georgiana Slough, three along the North Fork Mokelumne River and three along the South Fork Mokelumne River. The high frequency sampling boat will sample these river segments once during the week of study.

(3) Substantial Effluent-Nutrient Reduction: Post EchoWater (summer 2021) - We will sample using the sample methods and locations as described in (2) the Partial Effluent-Nutrient Reduction.

(4) Gradual Nutrient Reduction (winter and early spring 2020) - We will sample using the sample locations as described in (2) the Partial Effluent-Nutrient Reduction, with Mokelumne River samples collected behind a closed DCC. The high frequency sampling boat will sample nutrients, Chl-a, and other water quality variables along all these river reaches. Four sampling trips will be spread out from the time the DCC closes through the remaining winter/spring period.

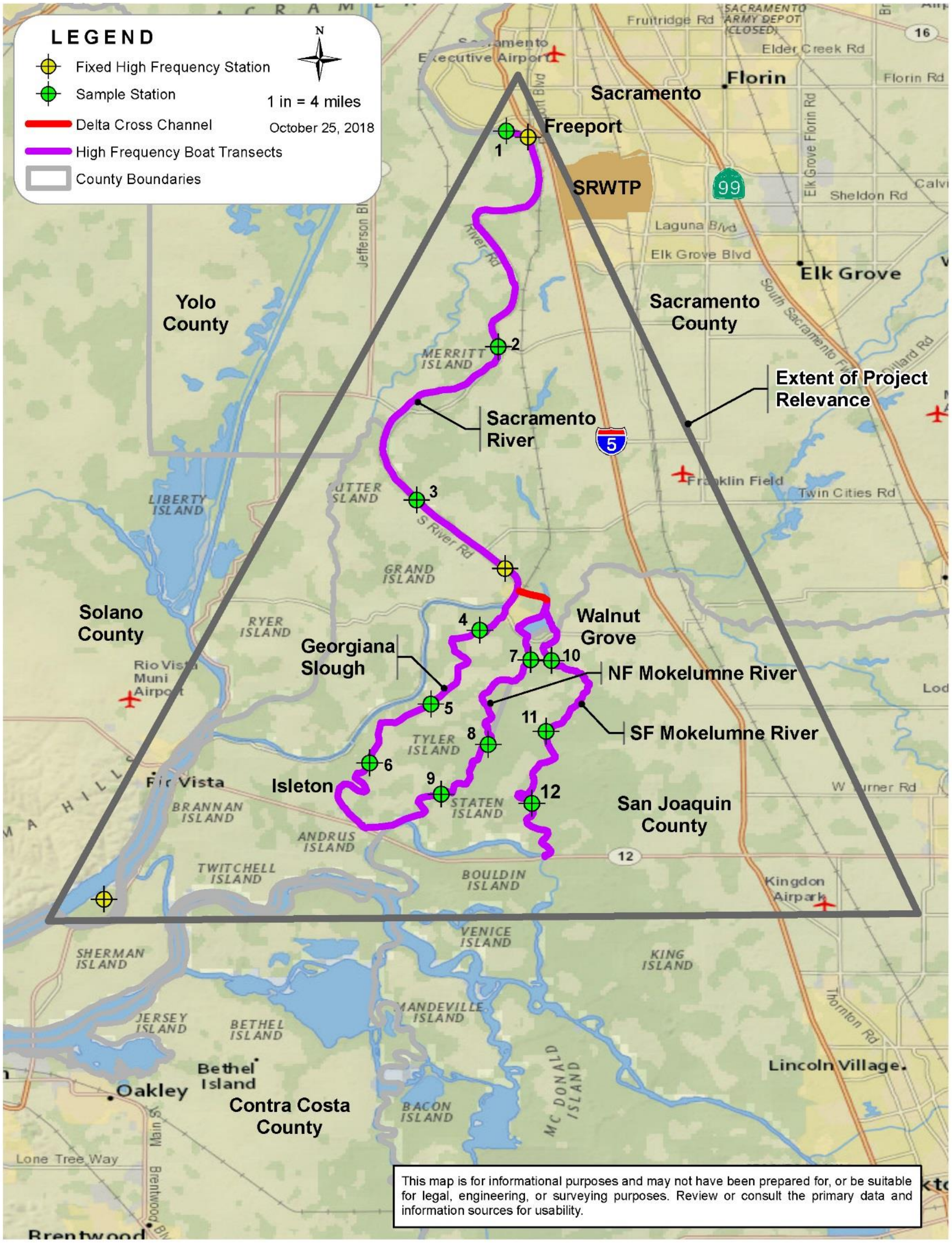

Figure 8. Project specific map, showing high frequency boat transects and fixed sample stations.

Tasks, Schedule and Deliverables

Task Number	Task Title	Deliverables and Key Project Milestones	Estimated Completion Dates
1.0	Project management	Coordinate and complete the four Sacramento River study scenarios. Deliver quarterly progress reports. Coordinate production of the final report, two manuscripts, and the presentations.	04/30/2023
2.0	Water quality sample collection and analyses	Collect or measure water temperature, dissolved oxygen (DO), pH, electrical conductivity, turbidity, chlorophyll a (Chl a), dissolved inorganic nutrients, and zooplankton samples during sampling events. Produce laboratory data reports listing analytical results from the collected grab samples.	12/31/2021
3.0	High frequency water quality boat mapping and analyses	Produce and analyze biogeochemical maps of the study area generated by onboard high frequency meters during each of four study scenarios to characterize changes in nutrients, phytoplankton community, and net ecosystem productivity over time.	07/31/2022
4.0	Plankton enumeration	Produce phytoplankton and zooplankton enumeration data reports for samples collected during the four study events.	12/31/2021
5.0	Phytoplankton growth sampling and analyses	Produce and analyze data reports on results from photosynthetically active radiation (PAR), variable fluorescence (Fv/Fm), and carbon (C) uptake measurements collected during sampling events.	07/31/2022
6.0	Zooplankton growth sampling and analyses	Produce and analyze reports on zooplankton collected during sampling events, including zooplankton enumerations, incubation growth rates, and volume determinations. Report on the observed relationships among environmental conditions and zooplankton abundance, growth, reproduction, and mortality. Report on the molecular identification of foods consumed by zooplankton. Inform quarterly progress reports, presentations, and manuscript writing.	07/31/2022
7.0	Clam collection and analyses	Collect clams during the four sampling events, analyze clam samples in the lab, and produce reports on the	07/31/2022

		calculated clam biomass and abundance for each sample location.	
8.0	Biogeochemical modeling	Develop model hydrology for water year 2020 for the Suisun-Delta Biogeochemical Model. Run the Biogeochemical Model for the two field scenarios to be studies in 2020. Report and analyze the output of model runs for the two study scenarios conducted in 2020.	07/31/2021
9.0	Reports and manuscripts	Draft final report will be delivered by January 31, 2023 (90 days prior to end of the CDFW agreement term). The Final Report will be delivered by February 28, 2023 (60 days prior to end of the CDFW agreement term). Two manuscripts will be submitted for peer-review by March 31, 2023 (30 days prior to the end of the CDFW agreement term).	02/28/2023
10.0	Presentations	At least one presentation at the State of the Estuary Conference 2019 (Poster based on preliminary results of 2019 field work). One or more presentations at the Bay-Delta Science Conference 2020 (Oral presentation based on 2019 field work, and preliminary results of 2020 field work). (3) One or more presentations at the State of the Estuary Conference 2021 (Oral presentation based on 2020 field work, and preliminary results of 2021 field work). (4) One or more presentations at the Bay-Delta Science Conference 2022.The last conference presentation that we plan to make during this contract would occur by December 31, 2022.	12/31/2022

Budget Summary

Institution	Amount Cost Share/In Kind	Amount Requested
Regional San	$793,763.40	$0
US Geological Survey*	$92,000.00	$382,010.00
Applied Marine Sciences	$0	$204,000.00
San Francisco State University	$0	$323,506.00
San Francisco Estuary Institute	$0	$141,593.00
BSA Environmental Services, Inc.	$0	$76,194.00
Local Conservation Corps - Sacramento Regional Conservation Corps	$0	$17,033.65
Total	**$885,763.40**	**$1,144,336.65**
Project Total (Cost Share, In Kind, and Requested)	**$2,030,100.05**	

* USGS Cost Share and In Kind. Cash: $32,000; Federal Matching Funds. In Kind: $60,000; Boat and instrument resources